

## DESCRIPTION

MAGNETIC NON-VOLATILE MEMORY DEVICE

## 5 FIELD OF THE INVENTION

The present invention relates to a magnetic non-volatile memory device, more specifically to the one provided with a magnetic shield structure for suppressing external magnetic field that may  
10 cause adverse effect on information stored therein.

## BACKGROUND ART

Information communication equipment, especially compact  
15 personal equipment such as mobile terminals have become very popular and this raises a strong need for higher performances such as higher integration, higher speed, lower power consumption, etc. of memories, logic devices and the like to be used in such equipment. In particular, non-volatile memory devices are considered to be  
20 essential in the ubiquitous age. In case of power shortage or a trouble of the equipment, or even in case of interruption of the connection due to a trouble between the server and the network, the non-volatile memory devices are able to hold the stored information and thus protect important information.

25 Currently, flash memories using semiconductor, FRAMs (Ferro-electric Random Access Memories) using ferro-electric material and the like are widely used as such non-volatile memory devices. However, flash memories have a disadvantage in that the writing speed is in the order of microseconds and thus very slow. On  
30 the other hand, FRAMs can be rewritten in the range of  $10^{12}$ - $10^{14}$ , thereby making them impossible to completely replacing SRAMs

(Static Random Access Memories) or DRAMs (Dynamic Random Access Memories) because of durability. Moreover, difficulty in microminiature processing of FRAMs is pointed out.

Incidentally, more recent portable equipment are designed to  
5 maintain non-used circuit blocks in stand-by condition for reducing unnecessary power consumption as small as possible. However, if a non-volatile memory having both functions of a high speed work memory and a large capacity storage memory is achieved, it is possible to avoid waist of power and memories. It is also possible to  
10 realize so-called instant-on function in which the system can be started immediately after power-on if a high speed and large capacity non-volatile memories are available.

Non-volatile memories that may achieve the above objectives are attracting a great deal of attention and include, for example, a  
15 magnetic memory that is known as a MRAM (Magnetic Random Access Memory) (See Wang et. al., IEEE Trans. Magn. 33 (1997), 4498). The MRAM device is a semiconductor magnetic memory utilizing magneto resistance effect based on the spin dependent conduction phenomenon that is peculiar to a nano magnetic material  
20 and is a non-volatile memory capable of holding stored information without externally supplying power.

Information writing in the MRAM device is carried out by combined magnetic fields of bit lines and word lines wired in matrix for inverting the magnetic spin of the cell at the cross point of the bit  
25 line and the word line, thereby recording the orientations as the information "1" or "0". On the other hand, information reading is carried out using the TMR (Tunnel Magneto Resistance) effect to which the magneto resistance effect is applied. The TMR effect is the phenomenon in which the resistance changes depending on the  
30 orientation of the spin. In case of reading the MRAM device, the information "1" or "0" is read out depending on whether the

resistance is high or low.

Additionally, since the MRAM device has a simple construction, it is easy to integrate. Also, since recording is made by rotating the magnetic moment, the number of rewritings can be very large. The access time is forecasted to be very high and is reported to be operable at 100 MHz (See R. Scheuerlein et. al., ISSCC Digest of Technical Papers, pp.128-129, Feb. 2000). As understood from the above, in conjunction with improved performance of the TMR materials in recent years, the MRAM devices are attracting a great deal of attention and there are increased hopes as high speed and large capacity non-volatile memories.

However, since the MRAM devices use a magnetic material for recording and holding the information, there is a possibility that the recorded information is erased or rewritten by the influence of external magnetic fields. Normally, the MRAM devices are mounted on a circuit board inside the electronic machine or equipment. Depending on kinds of electronic machine or equipment, as a progress of highly density mounting in recent years, mounted densely on a circuit board are various devices such as semiconductor devices, communication devices, miniature motors and the like other than the MRAM devices. Various mechanical components including an antenna, a power supply unit and the like are also installed inside the electronic machine or equipment to constitute a single apparatus together with the circuit board having the MRAM devices mounted thereon. This means that the MRAM devices are used in an environment of mixed magnetic fields over a wide frequency range including DC, low frequencies up to high frequencies. Accordingly, in order to put the MRAM devices into practical use, the MRAM devices need to be improved in resistance to external magnetic fields by means of improved mounting and/or magnetic shielding of the MRAM devices, thereby enhancing reliability of holding the recorded

information in such devices.

As examples of magnetic shielding of such MRAM devices, US Patent Nos. 5,902,690 and 5,929,772 propose magnetic shielding structures for MRAM devices. In particular, US Patent No. 5902690  
5 proposes to provide the MRAM device with a magnetic shielding characteristic by using insulation ferrite (MnZn and NiZn ferrites) layers that are soft magnetic metal oxides as a passivation film of the MRAM devices. On the other hand, US Patent No. 5,929,772  
10 proposes to form a permalloy which is a magnetic member having a high magnetic permeability inside a package, thereby preventing magnetic flux from penetrating inside the device.

However, such conventionally proposed shield structure for MRAM devices is not yet perfect and has a possibility to cause a problem by permitting magnetic flux to penetrate into the MRAM  
15 devices and to erase the stored information or overwrite.

In order to prevent magnetic flux from penetrating, it is necessary and the most important to dispose a magnetic material having a high permeability about the device, thereby providing a magnetic path so that magnetic flux does not penetrate into the  
20 device. In this point of view, the conventional methods to form a ferrite passivation film or forming a permalloy inside the package provide an incomplete magnetic shield structure because the magnetic path is not completely closed.

Moreover, in case of using a ferrite layer as the passivation  
25 film that is made by a film forming by the sputtering technique, since the ferrite is an oxide magnetic material, it is most likely to cause oxygen loss, thereby making it very difficult to use a complete ferrite layer as the passivation film. On the other hand, if the ferrite layer is formed by any technique other than sputtering, there encountered  
30 other problems such as increased manufacturing steps and cost in addition to decreased production yield.

Furthermore, in case of disposing permalloys at both top and bottom locations within the package, it is possible to obtain better shielding performance than the ferrite passivation film. However, since there is no magnetic interconnection between the top and bottom permalloys, the magnetic path is not established. Although this technique is effective in high frequencies, a large effectiveness is not expected for low frequency magnetic fields that are common to the MRAM devices. Even if one of the top and bottom permalloys is jointed to a ground layer of the device using an electrically conductive adhesive, the above mentioned drawback of not establishing the magnetic path is still applicable, thereby not providing significant magnetic shielding.

The present invention is made in consideration of the above circumstances and it is an object of the present invention to provide a non-volatile magnetic memory device that provides sufficient magnetic shielding performance for external magnetic fields over a wide frequency range.

## DISCLOSURE OF THE INVENTION

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The present invention is an MRAM device provided with a magnetic shielding structure for suppressing the influence of external magnetic fields characterized in that a magnetic shield layer is made from a soft magnetic metal on the surface of the device for suppressing penetration of magnetic flux into the device.

According to the above construction, since the magnetic shield layer is formed on the surface of the MRAM device, penetration of magnetic flux into the MRAM device is suppressed. Furthermore, since a soft magnetic metal is used for forming the magnetic shield layer, it provides not only the magnetic shield layer of higher permeability as compared to one made from a soft magnetic metal

oxide such as ferrite but also enabling to form the magnetic shield layer by the sputtering technique.

## BRIEF DESCRIPTION OF THE DRAWINGS

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FIG. 1 is a simplified drawing to show an exemplified construction of the MRAM device provided with a magnetic shielding structure according to the present invention.

10 FIG. 2 is a graph to show the relationship between the film thickness of the magnetic shield layer and the strength of the internal magnetic field.

FIG. 3 is a simplified drawing of the exemplified MRAM device for magnetically coupling the magnetic shield layer.

15 FIG. 4 is a simplified drawing of another example of the MRAM device for magnetically coupling the magnetic shield layer.

## THE BEST MODE FOR CARRYING OUT THE INVENTION

20 Now, embodiments of the present invention will be described hereunder by reference to the accompanying drawings.

FIG. 1 is a simplified drawing of an exemplified MRAM device provided with the magnetic shield layer.

25 The MRAM device 10 is formed with a TMR section 40 for storing and holding information at a transistor section 20 which is formed for switching by way of a word line 30 made from aluminum or the like and a bit line 50 made from aluminum or the like is also formed on the TMR device section 40. Moreover, a first magnetic shield layer 60a and a second magnetic shield layer 60b are formed respectively on the bottom surface of the transistor section 20 and on  
30 the top surface of the bit line 50 for suppressing penetration of magnetic flux from external magnetic fields.

In order to protect the MRAM device 10, a passivation film 70 made from silicon nitride (SiN) or the like is formed on the second magnetic shield layer 60b which is formed on the bit line 50 defining a device surface opposite to the bottom surface of the transistor section 20 which is a device surface at the mounting side of the MRAM device 10.

The transistor section 20 of the MRAM device 10 comprises the gate 22 formed on a silicon substrate 21 and the source 23 and the drain 24 formed on the silicon substrate 21. The gate 22 of the transistor section 20 is connected to the word line 30 of the MRAM device 10.

The TMR device section 40 can be roughly divided into a fixed layer 41, an insulation layer 42, a recording layer 43 and a barrier layer 44. The fixed layer 41 of the TMR device section 41 comprises a sequential lamination of a PtMn layer 41a of 300 Å in film thickness, an FeCo layer 41b of 30 Å in film thickness, a Ru layer of 8 Å in film thickness, an FeCo layer 41d of 20 Å in film thickness. The insulation layer 42 is an Al<sub>2</sub>O<sub>3</sub> layer of 15 Å in film thickness, the recording layer 43 is an FeCo layer of 30 Å in film thickness, the barrier layer 44 is a Ta layer of 50 Å in film thickness. Among these layers, the barrier layer 44 is connected to the bit line 50.

The first and second magnetic shield layers 60a, 60b are soft magnetic layers formed of a soft magnetic metal of the nano granular structure to achieve higher permeability or soft magnetic layers of a high permeability soft magnetic metal. The first magnetic shield layer 60a is formed on the bottom surface of the silicon substrate 21, while the second magnetic shield layer 60b is formed on the top surface of the bit line 50,

Although not shown in the drawing, it is possible to provide a separate barrier layer of the same material as the second magnetic shield layer 60b between the second magnetic shield layer 60ba and

the bit line 50. For example, if the second magnetic shield layer 60b is made from an electrically conductive material, an  $\text{Al}_2\text{O}_3$  layer or the like may be formed as the barrier layer. This construction insulates between the second magnetic shield layer 60b and the bit line 50, thereby improving reliability of the MRAM device 10. In case of forming such barrier layer, appropriate materials are chosen by considering various characteristics and relationship of the second magnetic shield layer 60b, the bit line 50 and the barrier layer to be formed such as the coefficient of thermal expansion other than the electrical conductivity.

In case of magnetic flux of external magnetic fields attempting to penetrate into the MRAM device 10 of the above construction, such magnetic flux is most likely to penetrate into the first and the second magnetic shield layers 60a, 60b among elements constituting the MRAM device 10. This is because the first and the second magnetic shield layers 60a, 60b are made from soft magnetic material having high permeability, thereby enhancing the tendency of passing magnetic flux through them. Moreover, once magnetic flux penetrated into either one of the first and the second magnetic shield layers 60a, 60b, it tends to flow inside such magnetic shield layer. Subsequently, even if magnetic flux may get out of the magnetic shield layer, it tends to penetrate into another magnetic shield layer. In other words, in such MRAM device 10, a magnetic path is secured by the first and the second magnetic shield layers 60a, 60b. Accordingly, in the MRAM device 10, penetration of magnetic flux into the TMR device section 40 where information is recorded and held is effectively suppressed.

Now, a method of forming the magnetic shield layer of the MRAM device 10 as constructed hereinabove will be described.

The first and the second magnetic shield layers 60a, 60b of the nano granular structure may be formed in accordance with a regular

nano granular forming technique. For example, a sputtering is carried out on the surface where the nano granular film is formed by using a  $(\text{Co}_{0.92}\text{Fe}_{0.08})_{90}\text{Al}_{10}$  target, thereby forming an FeCo-Al-O nano granular film comprising a non-magnetic layer of  $\text{Al}_2\text{O}_3$  at the grain boundary of an FeCo layer which is a magnetic layer (See Journal of Institute of Applied Magnetic of Japan No. 25, pp871-874, 2001). Other than the above mentioned Fe-Al-O nano granular film, the nano granular film may be any nano granular film having a composition of Fe-Al-O, Co-Al-O or the like.

Also, the high permeability soft magnetic metal to be used for the first and the second magnetic shield layers 60a, 60b may be, for example, Fe, FeCo, FeSi, FeSiAl, FeAl or NiFe. Even in case of forming the nano granular film using such materials, it is possible to film form by the sputtering technique as is the case of forming the nano granular film.

In case of making the MRAM device 10 provided with the first and the second magnetic shield layers 60a, 60b which are formed in the manner as described hereinabove, for example, the transistor section 20 is first formed on a wafer constituting the silicon substrate 21 through a normal processing before being placed in a sputtering chamber. Subsequently, the word line 30, many layers comprising the TMR device section 40 and the bit line 50 are sequentially film formed in lamination by the sputtering technique. The first magnetic shield layer 60a and the second magnetic shield layer 60b are formed respectively on the bottom surface of the transistor section 20 and on the top surface of the bit line 50 by the sputtering technique using the target which has been described hereinabove as an example.

After forming the second magnetic shield layer 60b, a passivation film 70 is formed thereon. Subsequently, necessary processes such as making holes in the passivation film 70 and the

second magnetic shield layer 60b for forming pads on the passivation film 70 are carried out before dicing, thereby forming discrete MRAM devices 10 each covered with the passivation film 70 on the top surface.

5           Other than the above example, the MRAM device 10 may be made, for example, by forming the first magnetic shield layer 60a on the bottom surface of the silicon substrate 21 prior to forming the TMR device section 40. Then, it is placed in a sputtering chamber to form only the second magnetic shield layer 60b after forming the bit  
10 line 50. In this case, the first magnetic shield layer 60a which is formed in advance can be formed by any film forming technique other than the sputtering.

          Moreover, the MRAM device 10 may be formed, for example, by placing a semi-completed product having the transistor section 20,  
15 the word line 30, the respective layers constituting the TMR device section 40 and the bit line 50 through appropriate processing, thereby forming the first and the second magnetic shield layers 60a, 60b by the sputtering technique. It is to be noted in this case that the first magnetic shield layer 60a may be formed in advance by any  
20 technique other than the sputtering and forming only the second magnetic shield layer 60b by the sputtering technique.

          As shown in the above examples, in fabricating the MRAM device 10, the first and the second magnetic shield layers 60a, 60b may be formed by the sputtering technique. And what is important  
25 herein is that the composing elements of the targets which are used in forming the soft magnetic layers constituting the first and the second magnetic shield layers 60a, 60b are common to a part of the elements of the target to be used for forming various layers of the MRAM device 10.

30           In other words, targets such as Fe, Co, Pt, Mn, Al and the like for forming the TMR device section 40 and the targets for forming the

first and the second magnetic shield layers 60a, 60b may be provided in a single sputtering chamber, thereby enabling to form the various layers in a common chamber. This means that any possibility of introducing impurities that may adversely affect the storage and holding characteristic of the MRAM device 10 can be suppressed at the time of forming the MRAM device 10 having the first and the second magnetic shield layers 60a, 60b. Additionally, it helps to cut production cost and improves production yield.

It is to be noted that the first and the second magnetic shield layers 60a, 60b may be made by various conventional film forming techniques such as a plating technique, a spin coating technique or the like other than the above mentioned sputtering technique. Moreover, an aerosol deposition (AD) technique in which fine particles of raw materials composing of a film are made in aerosol and are bombarded onto an object on which the film is formed can be used for forming the first and the second magnetic shield layers 60a, 60b because it is useful for easily forming a thick film at a high speed.

Furthermore, as described hereinabove, it is possible to form the first and the second magnetic shield layers 60a, 60b by using different film forming techniques from each other. For example, the first magnetic shield layer 60a is film formed on the bottom surface of the silicon substrate 21 by the spin coat technique, while the second magnetic shield layer 60b is film formed on the top surface of the bit line 50 by the sputtering technique. At the time of choosing each film forming technique, it is necessary to consider productivity of the MRAM device 10, film thickness of the magnetic shield layer to be formed and the like.

Now, the magnetic shielding characteristic by the magnetic shield layer will be described.

An evaluation of the magnetic shielding characteristic is made on the magnetic shield layer made from a soft magnetic layer of the

nano granular structure with the composition of Fe-Al-O. The Fe-Al-O nano granular film is formed by firstly sputtering Fe and Al and then making the sputtering chamber an oxidation atmosphere to allow natural oxidation. It is to be noted at the time of  
 5 characteristic evaluation that measurements of saturation magnetization and anisotropic magnetic field are made by film forming Fe-Al-O on separate substrates while applying a magnetic field.

The saturated magnetization of the formed nano granular film  
 10 was 1.1T, the coercive force was 2.3A/m and anisotropic magnetic field was 6kA/m. Permeability was  $\mu' = 200$  and  $\mu'' = 20$  (both at 100 MHz) and tendency was seen that loss becomes higher at high frequency.

Additionally, MRAM devices having the magnetic shield  
 15 layers and MRAM devices having no magnetic shield layers are fabricated. External magnetic fields are applied to these MRAM devices to measure strength of magnetic field inside the MRAM device. Measurements were made by externally applying 200Oe magnetic field onto the MRAM devices having the magnetic shield  
 20 layer up to 200nm.

FIG. 2 is a graph to show the relationship between the film thickness of the magnetic shield layer of the MRAM device and the strength of magnetic field inside the device. In FIG. 2, the horizontal axis represents the film thickness (nm) of the magnetic  
 25 shield layer, while the vertical axis represent the strength of magnetic field (Oe) inside the device.

As shown in FIG. 2, strength of the internal magnetic field due to application of 200 Oe external magnetic field onto the MRAM device decreases as the film thickness of the magnetic shield layer  
 30 increases. In general, the inverting magnetic field of the MRAM device is about 30 Oe. Judging from the result as shown in FIG. 2,

the magnetic shield layer is required to be as thick as about 170 nm in order to reduce the external magnetic field less than the above value. However, since the optimum film thickness of the magnetic shield layer depends on the magnetic environment at the location where the MRAM device is disposed and the material of the magnetic shield layer, the measurement results do not mean that all MRAM devices should have the film thickness equal to about 170 nm. The relationship in FIG. 2 shows that the internal magnetic field can be adjusted by varying the film thickness of the magnetic shield layer. It is therefore possible that the film thickness can be set in response to the magnetic environment of the MRAM device.

As described hereinabove, in consideration of problems associated with conventional technique such as difficulties in both fabrication facilities and performance of forming the ferrite layer after formation of the MRAM device using a single sputtering chamber and relatively low permeability of the ferrite layer as compared with a soft magnetic metal even if it is formed, the present invention features in forming a magnetic shield layer using soft magnetic metal.

The magnetic shield layer of soft magnetic metal may be formed to have the nano granular structure or may be made from soft magnetic metal having high permeability. Since soft magnetic layers are chosen to have partly common composing elements to elements of the targets to be used for forming various layers of the MRAM device, a common sputtering chamber that is used for forming the layers of the MRAM device can be used for forming the soft magnetic layer. Accordingly, the MRAM device provided with magnetic shield layers can be fabricated efficiently and the fabrication steps can be suppressed to the minimum, thereby reducing the fabrication cost.

The MRAM device provided with the magnetic shield layers as

formed in the above manner is able to suppress the magnetic flux penetrating from the external magnetic fields down to a level below the inverting magnetic field strength of the recording layer, improve storage and hold stability and enable to be used under sever magnetic  
5 field environment.

Moreover, the aforementioned MRAM device 10 may be designed to have a construction in which both of the first and the second magnetic shield layers 60a, 60b formed on the bottom and top surfaces of the MRAM device 10 are magnetically coupled together.  
10 FIG. 3 is a simplified drawing to show an exemplified construction of the MRAM device in which the magnetic shield layers are coupled together. It is to be noted in FIG. 3 that constituent elements equivalent to those in FIG. 1 use the same reference numerals and their detailed descriptions are omitted.

15 The MRAM device 10 is provided with the first and the second magnetic shield layers 60a, 60b on the top and the bottom surfaces thereof, respectively. The MRAM device 10 is mounted on a lead frame 80 at the side of the first magnetic shield layer 60a and is provided with the passivation film 70 on the second magnetic shield  
20 layer 60b. The MRAM device 10 is also formed with a third magnetic shield layer 60c on the side surface. The third magnetic shield layer 60c is designed to magnetically couple the first and the second magnetic shield layers 60a, 60b.

In the MRAM device 10 provided with such magnetic  
25 shielding structure, a magnetic path is formed through the first, the second and the third magnetic shield layers 60a, 60b and 60c. Accordingly, magnetic flux from external magnetic fields do not penetrate inside the MRAM device 10, rather conducted to the first, the second and the third magnetic shield layers 60a, 60b and 60c,  
30 thereby suppressing penetration into the device. Furthermore, the magnetic flux once entered into either one of the first, the second and

the third magnetic shield layers 60a, 60b and 60c tends to be prevented from leaking out of the end of such magnetic shield layer or tends to flow into adjacent magnetic shield layer, thereby effectively shielding the MRAM device 10 from the external magnetic fields.

The third magnetic shield layer 60c is formed with a soft magnetic layer in the same manner as the first and the second magnetic shield layers 60a, 60b. A sputtering technique, a plating technique, a spin coat technique, an AD technique or the like may be used for forming the third magnetic shield layer 60c. The choice of the techniques for forming the third magnetic shield layer 60c is made in consideration of the construction and productivity of the device on which the third magnetic shield layer 60c is to be formed, film thickness of the third magnetic shield layer 60c to be formed, or the like.

It is to be noted that the third magnetic shield layer 60c may be formed on one side surface of the MRAM device 10 as shown in FIG. 3. However, the magnetic shield layer is preferably formed so as to cover the entire circumference of the MRAM device 10 for assured suppression of penetration of the magnetic flux.

It is also possible that the lead frame 80 has integral protrusions of soft magnetic member or protrusions each covered with soft magnetic material on the surface thereof for locating the MRAM device 10 thereat. FIG. 4 is a simplified drawing to show another exemplified construction of the MRAM device in which the magnetic shield layers are magnetically coupled together. However, it is to be noted that the constituting elements equivalent to those in FIG. 3 have the same reference numerals and their detailed descriptions are omitted herein.

As shown in FIG. 4, the MRAM device 10 provided with the first and the second magnetic shield layers 60a, 60b is mounted on

the lead frame 80 having an integral protrusion 81 made from a soft magnetic material or covered with a soft magnetic material on the surface thereof. The protrusion 81 is formed to extend in the vertical direction with respect to the lead frame 80 in such a manner  
5 to be located on the side surface of the MRAM device 10 that is mounted on the lead frame 80. When mounting the MRAM device 10 on the lead frame 80, end portions of the first and the second magnetic shield layers 60a, 60b are made in contact with the protrusion 81 or are in the close proximity to it.

10 It is to be understood that such protrusion 81 is able to provide the similar advantages to the third magnetic shield layer 60c as shown in FIG. 3 and effectively provides magnetic shielding of the MRAM device 10 from external magnetic fields. It is also possible to surely suppress penetration of magnetic flux if the protrusion 81 is  
15 formed so as to enclose the MRAM device 10.

Although the first and the second magnetic shield layers defining the soft magnetic layers are formed at the two locations, i.e., on the device mounting surface and the opposite surface of the MRAM device 10 in the above description, it is of course possible to  
20 form on only the device mounting surface or the opposite surface to the device mounting surface in order to obtain a certain magnetic shielding of magnetic fields in a given frequency range.

As described hereinabove, according to the present invention, the magnetic shield layer is formed on the surface of the MRAM  
25 device by using soft magnetic metal. By this construction, penetration of magnetic flux inside the MRAM device is suppressed. Accordingly, even if external magnetic fields are applied, the magnetic flux penetrated into the recording layer is suppressed below the inversion strength of magnetic field of the recording layer,  
30 thereby improving stability of the storage and hold of the information and realizing MRAM devices which can be used under severe

magnetic field environment.

Moreover, by using soft magnetic metal as the magnetic shield layer, the magnetic shield layer can be formed by the sputtering technique, particularly composing elements can be partly shared as  
5 elements of the targets to be used for forming various layers composing the MRAM device by the sputtering technique, thereby enabling to form various layers of the MRAM device in a single sputtering chamber. As a result, the MRAM device can be fabricated efficiently and can reduce the production cost.